NGST MISSION ARCHITECTURE IPT
Activity Report for March-June 1997

Pierre Bely

24 June 1997

NEXT GENERATION SPACE TELESCOPE

NGST

CURRENT ACTIVITIES

- **End-to-end model:**
  - Work has been very fruitful and is approaching completion for the yardstick model.
  - Active participation of

    GSFC (Gary Mosier, Mike Femiano, Kong Ha, Mike Choi, Chuck Perrygo)

    STScI/JHU (Richard Burg)

    MSFC (Dave Jacobson, John Rackozy, Larry Craig, Richard Schunk)

    JPL (Dave Redding, Andy Kissel)

    Langley (Keith Belvin)

    Phillips Lab (Kevin Bell)
  - Special thanks to Dave, Richard, Mike, Kong, Gary and Andy for long hours and for their dedication !
  - A real team work and a great team working across centers and across the country. A model for how NGST will be carried out.
- **Straylight analysis.**

  Straylight preliminary analysis completed. Satisfactory results
- **Sky coverage study**

  Study of the sky coverage requirements and a better definition of the deep survey sweet spots completed.

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CURRENT ACTIVITIES (Ctd)

- **Cost modeling.**

  Cost modeling study by ORA evaluating:

  - differences between segmented and monolithic systems
  - influence of the major system level factors (aperture, spectral band)

  is nearing completion.

- **Thermal study.**

  The thermal model is being updated and exercised to:

  - evaluate the OTA + SIM temperature vs sunshield's design parameters (size, number of layers, surface characteristics)
  - evaluate the mirror temperature gradient vs type of mirror blank and line-of-sight/sun angle
  - evaluate the temperature variation vs location on orbit for the 1x3AU case.
  - conclude on the effects on instrumental background and calibration needs.

  Work at GSFC impeded by lack of manpower and software problems. First two items have been worked by MSFC. So far this area has not been part of the integrated model, but it should be.

- **Contamination.**

  Eve Wooldrige, Shaun Thomson and Chuck Perrygo have conducted a preliminary study to evaluate the level of contamination to be expected due to shield, structure outgassing, and propulsion (orbit maintenance and momentum dumping). Contamination does not seem to be an issue for NGST.

NGST MONOGRAPHS

- **NGST monographs are intended to**
  - document the studies done by the government team
  - communicate findings to industry and astronomical community.
- **First series will include:**
  - Straylight (Mahelick, Bely, Petro)
  - Meteroid damage (Petro)
  - First order dynamic model (Bely, Burg et al)
  - Launchers (Purves)
  - Guiding sensor (Burg, Bely, Roddier)
  - Contamination - preliminary analysis (Wooldridge et al)
  - Sunshield design issues (thermal, deployment and dynamics)
  - End-to-end modeling - First results (Simulation team)

NGST END-TO-END MODELING

Agenda

Introduction and overview	Pierre Bely
Structural modes	Chuck Perrygo
Reaction wheel model	Gary Mosier
Simple model results	Pierre Bely and Richard Burg
Modeling walk-through	Richard Burg
Simulation results	Mike Femiano and Dave Redding
Demo	Gary Mosier and Dave Redding

NGST END-TO-END MODELING

OVERVIEW

Pierre Bely

24 June 1997

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END-TO-END MODELING -- OVERVIEW

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Goals of the simulation:

- **Establish what is needed for satisfying LOS < 7 mas and WFE <100 nm rms**
  - Structure optimization
  - Need for isolation,
  - Specifiy allowable wheel noise
  - Determine sunshield requirements (for PM stability during repointing)
- **Establish "optimized" overall error budget**
  - Figure errors, alignment errors, wf control errors
  - dynamics effects
  - thermal effects
- **Compare primary mirror schemes**
  - Beryllium, Ni, Fused silica lightweighted mirror with low density actuators
  - Fused silica facesheeet with high density actuators
- **Develop calibration schemes**
  - bootstrapping
  - reinitialization following slews

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END-TO-END MODELING -- OVERVIEW

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END-TO-END MODELING -- OVERVIEW (Ctd)

Model validation

- **Structural FEM validated by**
  - individual inspection of the first 100 modes
  - comparison to hand calculations for the main modes
- **Optics validated by exercising each optics element (tilt, piston) and comparing to direct analysis**
- **Thermal model: inspection and comparison to hand calculations**
- **ACS: validated by exercising the model for various types of commands and comparison to existing systems (XTE, HST)**
- **FSM: model originally supplied by manufacturer, modified and tested locally**
- **RW model: based on HST wheels**

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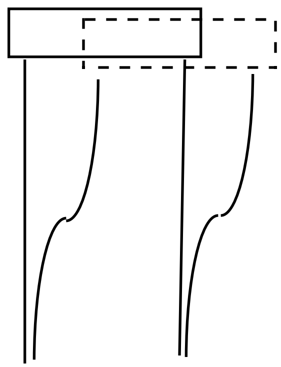
END-TO-END MODELING -- OVERVIEW (Ctd)

Secondary mirror stability is critical

Current design:



Secondary mirror motion is mostly in decenter

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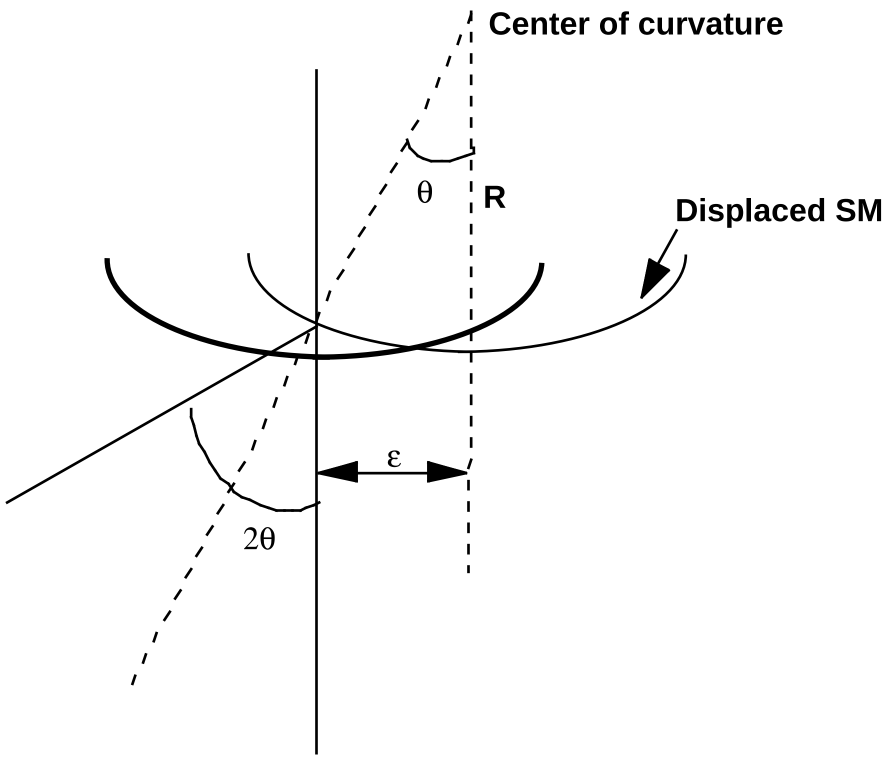
END-TO-END MODELING -- OVERVIEW (Ctd)

Secondary mirror stability is critical



A SM decenter of ε induces an angular dispacement of the image of 2θ.

R θ = ε /

where R = 1.8 m

At the focal plane, this corresponds to:

H δ = 2θ

where H is the distance of the SM to the first focus (H =10m).

On the sky this is equivalent to:

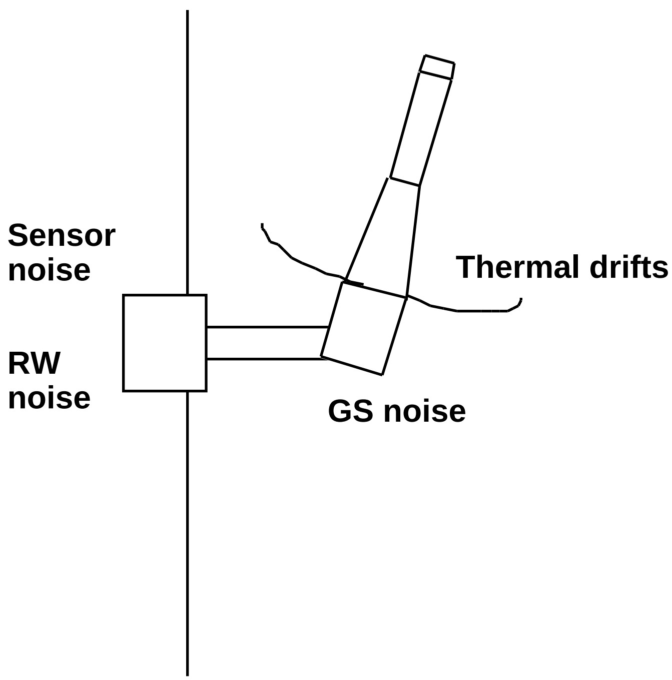
F = 2 εH /αR=Fδ radians

where F is the focal length of the first focus (F=120m).

To keep image motion (α) at less than 2 mas, the SM decenter (ε) must be less than 0.1 micron !

END-TO-END MODELING -- OVERVIEW (Ctd)

Disturbance sources



ACS sensor noise	~1.5” before filtering
Guide star sensor noise	~3.5 mas (mag 16 star)
Reaction wheel noise	function of wheel speed squared
Thermal drifts	a few deg K following large slew

We neglect so far micro-lurching and thermal creaks. Need to confirm that they are indeed negligible or model correctly.

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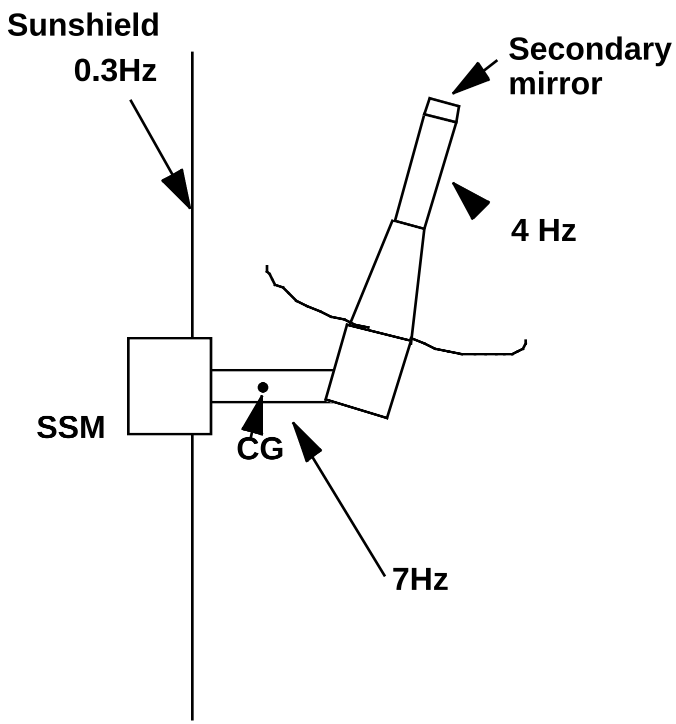
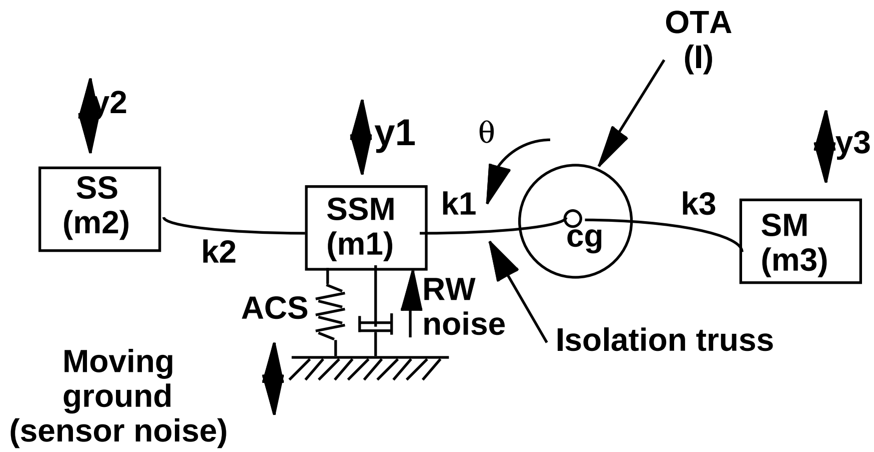
END-TO-END MODELING -- OVERVIEW (Ctd)

Validation with Simplified 4 DOF model



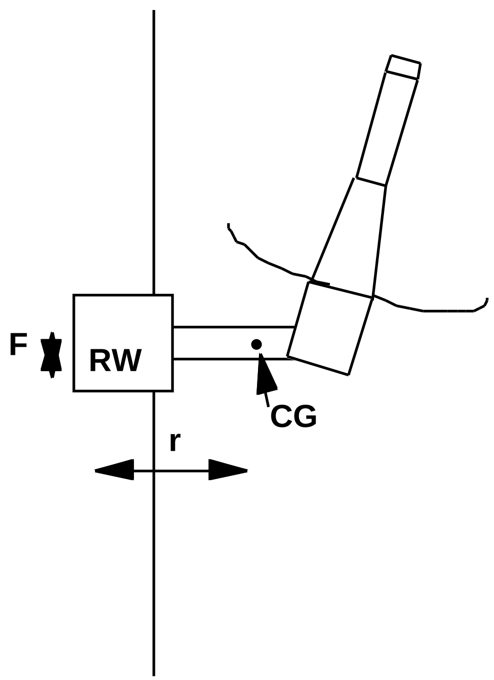


Single axis 4-DOF model

PB:28-Jul-97

END-TO-END MODELING -- OVERVIEW (Ctd)

NGST “offset design” amplifies RW disturbances



- Mirror actuators and SIM mechanisms are not active during observations. The only source of dynamic disturbance is the reaction wheels.

- Wheel unbalance and bearing runouts induce force (and torque) proportional to the square of the wheel speed (ω).

$$F = u\,\omega^2 \sin \omega t$$

This reaction wheel noise has two effects:

1 - it excites flexible modes (e.g. secondary mirror) if close to resonnance
2 - it creates an overall angular motion of the entire observatory and result in a LOS jitter

$\theta'' = F\,r / I$ I= overall moment of inertia around cg

amplitude: $\theta_{max} = (1/\,\omega^2)\ u\,\omega^2\, r / I = u\, r / I$

This last effect is independant of wheel speed and directly proportional to the distance of the RW to the overall cg.

r ~ 3 m I ~20000 kgm2 , and for typical off the shelf wheel:
$u \sim 1.5\ 10^{-4}\ Ns^2$ so that

$\theta = 5\ 10^{-8}$ radians = 10 mas

Hence this is a critical issue in our yardstick design. Note that the bandwidht of the FSM correction is not enought to correct for these effects. Note also that this effect would much reduced for a compact design (a la LMSC).

END-TO-END MODELING -- OVERVIEW (Ctd)

HST and NGST compared

	HST	NGST
Inertia (Kg m2)	70 000	20 000
Lowest mode (Hz)	0.1	0.3
Primary mirror mode (Hz)	60	10
Secondary mirror mode (Hz)	80	4
ACS bandwidth (Hz)	0.5	0.02
Gyro noise (arcsec)	0.01	0.07
Tracker noise (arcsec)	0.005*	2**
Update rate (Hz)	1	4
LOS error (arcsec)	0.003	0.2

* FGS
* as used by the ACS, 0.003” with guide star sensor

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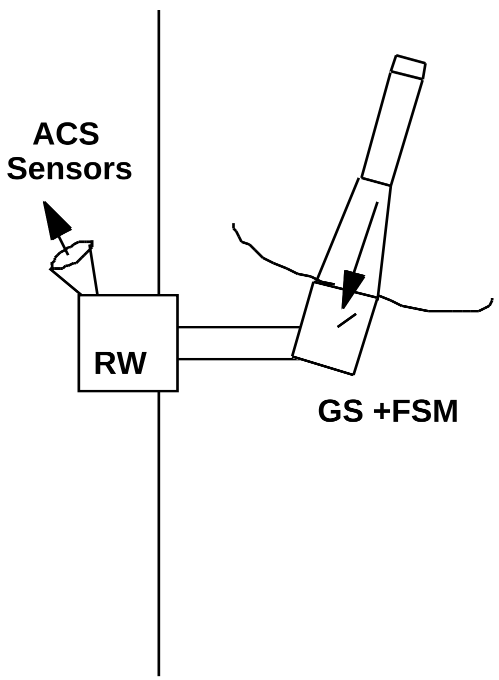
END-TO-END MODELING -- OVERVIEW (Ctd)

NGST yardstick attitude control rationale



1. SSM needs to be warm for electronics and reaction wheels

2. SSM must be separate from OTA to minimize heat conduction

3. Isolation truss flexibility would lead to ACS unstability if the sensors were on OTA while RW are in SSM. Sensors and RW must be colocated in the SSM

4. The ACS is not capable to give OTA stability to mas level

5. This requires an image compensation system (Guide star sensor and FSM) in OTA.

6. Body pointing is NOT an option for our NGST “offset” design

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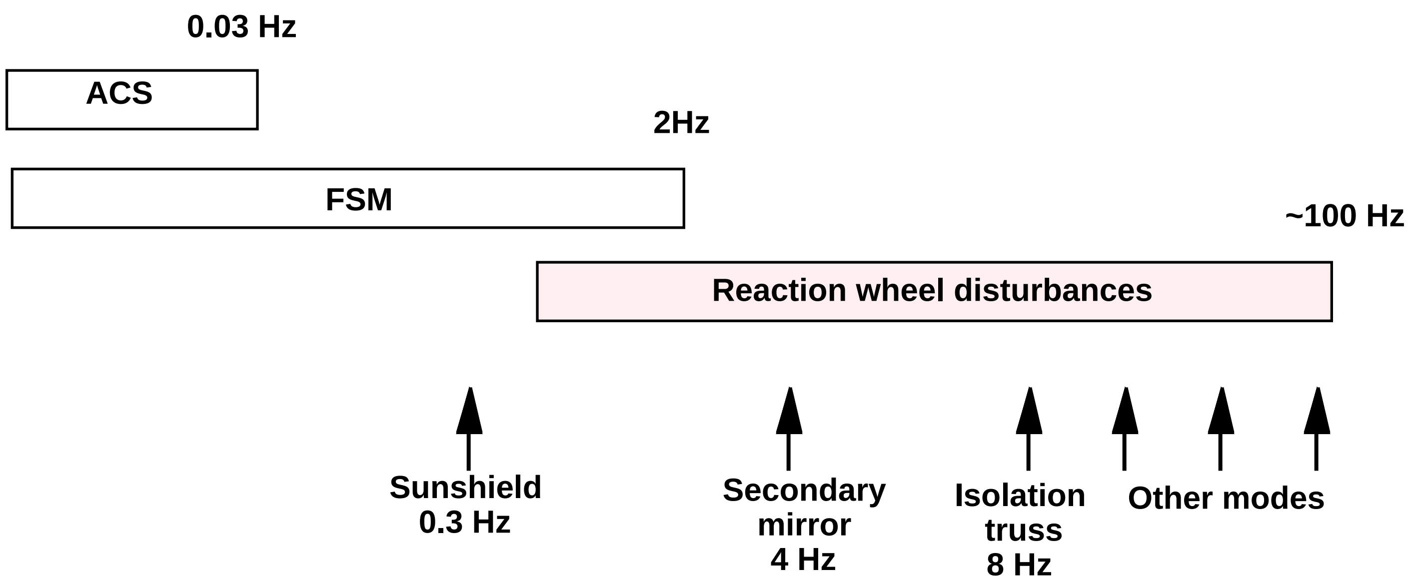
END-TO-END MODELING -- OVERVIEW (Ctd)

Bandwidth compared



The ACS has no authority to control any of the flexible modes

The FSM can suppress the sunshield mode

Excitation of the higher modes must be minimized

NEXT GENERATION SPACE TELESCOPE

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END-TO-END MODELING -- OVERVIEW (Ctd)

Lessons of the modeling effort:

- As expected, a detailed simulation is a great tool to uncover design errors (I.e. FSM optics) and optimize error budgets.
- Harmonizing models, units and coordinate systems was a bigger task than expected
- Internal consistency is important. Hardcoding parameters should be avoided as it leads to inconsistency (e.g. inertia, mass, flexible modes etc.. should be derived from the FEM model and not input separately)
- Arguably, the most difficult task was to find the proper balance between simplifications and high fidelity (simple models may overlook fundamental problems, detailed models take time to develop and may increase run time tremendously)
- High fidelity FEM model took too long to run and had to be simplified
- Model time/running time ratio of 15 was at the limit of the practical during the debugging period.
- Simple models are needed for validation and engineering insight - also complex simulation are cumbersome to use for rapid parametric studies (equiv to prototyping)
- Integrated modeling is a great team builder, but requires experienced and motivated people (double tennis syndrome)

END-TO-END MODELING -- OVERVIEW (Ctd)

Further model improvements

- Structure model to be refined - only where it counts! - (Larry Craig - MSFC and Andy Kissel - JPL)
- Active Isolation model to be developed (John Spanos - JPL)
- Primary mirror actuator to be modeled (Keith Belvin - Langley)
- Guide star model to be refined to include WF errors
- FSM to be modeled with higher fidelity (John Rakoczy - MSFC)
- Refine, expand and integrate thermal model
- Modify optical model (FSM issue)

END-TO-END MODELING -- OVERVIEW (Ctd)

Near term tasks with current model

- **Alternate structural design to be investigated (i.e. Secondary mirror support)**
- **Explore widening ACS bandwidth in the presence of flexible modes**
- **Explore feeding GS signal into ACS (problem due isolation truss flexibility)**
- **Investigate other sources of disturbances (microlurching, thermal creaks)**
- **Push the simulation to its full potential by combining and trading the various contributing factors (figure errors, jitter, WFE, etc..) and evaluate overall image quality over an observation elementary period (1000 s)**
- **Perform parametric study**
- **Refine, expand and integrate thermal model**
- **Modify optical model (FSM issue)**

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END-TO-END MODELING -- OVERVIEW (Ctd)

Schedule

- Baseline case (Be mirror on GE structure) : essentially complete
- Be mirror on Be structure: 30 July
- Fused silica mirror on GE structure: 30 July
- Fused silica facesheet on high density actuators: 30 September
- LMSC design (3 AU, monolithic mirror, integrated OTA/SSM/sunshield design: 30 September (with contractor assistance)

END-TO-END MODELING -- OVERVIEW (Ctd)

Preliminary conclusions and recommendations

- **Current design appears adequate but requires either quiet wheels (HST type) or isolation**
- **This trade need further exploration.**
  - Quiet wheels cure the problem at the source. Isolation is never perfect
  - On the other hand, if there are other disturbances, isolation may be the panacea that we need
- **In all cases it may be good to include quiet wheel in the technology development program (magnetic bearings?) in parallel to isolation**

END-TO-END MODELING

Reaction Wheel Disturbances

HST wheels (w/o isolation)

END-TO-END MODELING

Reaction Wheel Disturbances

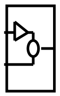
Model representation

$$F = u_s \, \omega^2 \; \sin \; \omega \, t$$

$$T = u_d \, \omega^2 \; \sin \; \omega \, t$$

END-TO-END MODELING

System model - First level



END-TO-END MODELING

System model - 2nd Level - Dynamics

2

END-TO-END MODELING

System model - 2nd Level - Optics

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END-TO-END MODELING

System model - 2nd Level - LOS control

1

END-TO-END MODELING

System model - 2nd Level ACS

$\boxed{1}$

System model - 2nd Level Vibration Isolation

ISO

NGST END-TO-END MODELING

SIMPLE MODEL

Richard Burg

24 June 1997

END-TO-END MODELING -- SIMPLE MODEL

Goals of the simple model:

- **Validate the full model by estimating contribution of the major disturbance sources (ACS sensor noise*, RW noise, GS noise) on line of sight.**
- **Gain engineering and physical insight by limiting complexity - the “human factor”**
- **Perform first order parametric study to gain design insight.**

Note: No attempt to model the wave front error as this would imply higher complexity reaching the level of the full model.

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END-TO-END MODELING -- SIMPLE MODEL

Reaction wheel disturbance model:

Power Spectrum Magnitude (dB)

END-TO-END MODELING -- SIMPLE MODEL

Effect of reaction wheel disturbance on the Secondary which induces LOS error

Sec-CG (arcsec/newton)

$\sigma =$ **1.0 mas w/ FSM**

END-TO-END MODELING -- SIMPLE MODEL

Effect of reaction wheel on observatory CG

CG (arcsec/newton)

$\sigma = $ **0.06 mas w/ FSM**

END-TO-END MODELING -- SIMPLE MODEL

Effective filtering function of fast steering mirror

FSM LOS Rejection

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END-TO-END MODELING -- SIMPLE MODEL

Effect of ACS noise on LOS jitter due to secondary mirror motion

Secondary-CG effect on LOS(arcsec) to arcsec in

$\sigma =$ **0.01 mas w/ FSM**

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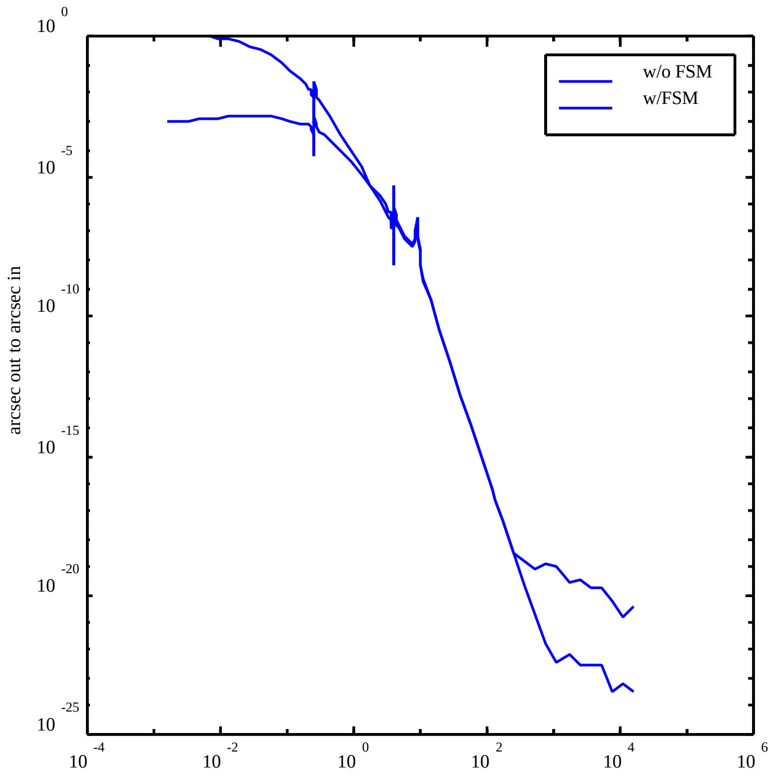
END-TO-END MODELING -- SIMPLE MODEL

Effect of ACS noise on observatory cg



$\sigma =$ **110 mas w/o FSM**
$\sigma =$ **0.4 mas w/ FSM**

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END-TO-END MODELING -- SIMPLE MODEL

Line of sight jitter due to secondary mirror motion as a function of truss natural frequency

LOS Jitter (mas)

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END-TO-END MODELING -- SIMPLE MODEL

Line of sight jitter due observatory CG motion as a function of isolation truss natural frequency

LOS Jitter (mas)

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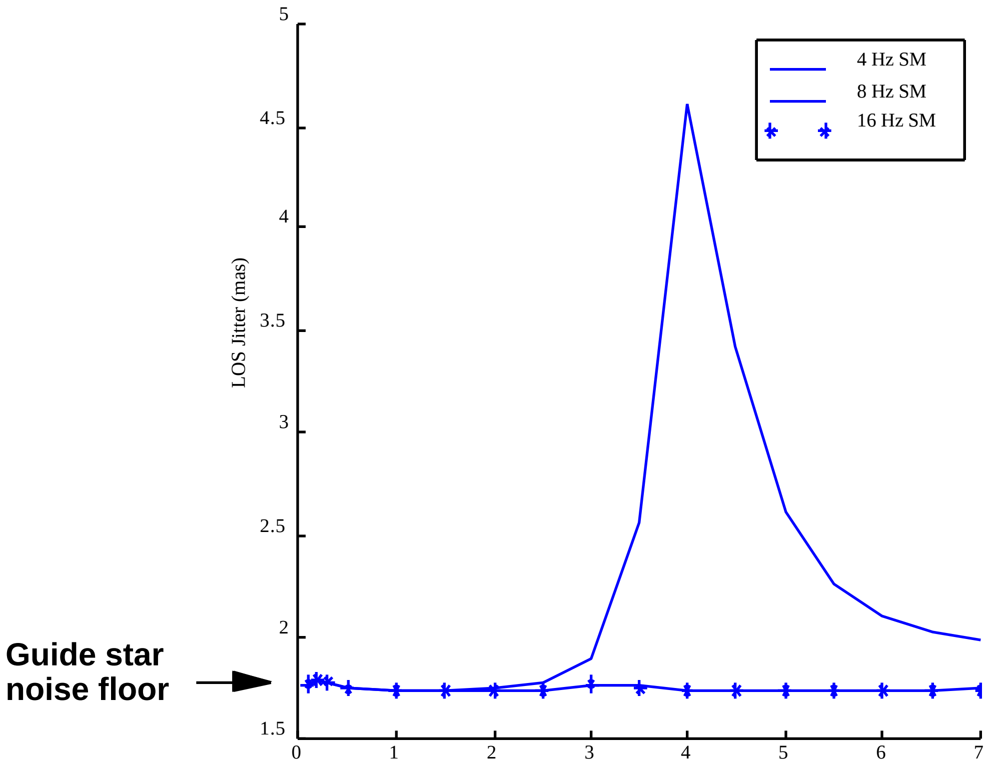
END-TO-END MODELING -- SIMPLE MODEL

Overall line of sight jitter due to all 3 disturbances as a function of

- **isolation truss natural frequency**
- **secondary mirror support natural frequency**



END-TO-END MODELING -- SIMPLE MODEL

Conclusions:

- Simple model and full model are in agreement.
- The FSM effectively filters ACS noise to meet design goals
- Overall line of sight jitter is dominated by the guiding sensor noise of ~2mas - limited by the sky and FOV.
- The Hubble reaction wheel model meets design goals but effects of resonances are important
- Parametric study must be redone with the full model since resonance coupling has been shown to be important.
- It will be important for the final design to be robust and possibly adaptable to cope with unmodelled resonances and changes due to zero gravity.

NGST END-TO-END MODELING

LOS JITTER

Mike Femiano

24 June 1997

END-TO-END MODELING -- LINE OF SIGHT JITTER

Preliminary Conclusions:

- **With Hubble-type wheels, worst case LOS jitter is less than 4mas rms which meets specs**
- **When RWA do not excite major resonances, jitter is essentially due guide star noise and is about 2.8 mas**
- **For the worst resonance case (Isolation truss 7Hz), LOS jitter contributions are:**
  - guide star noise 82 %
  - Reaction wheel 18 %
  - ACS sensor noise: negligible.
- **When wheel noise is increased by 10, LOS jitter increases to 5.7 mas and is dominated by RW noise.**
- **Using off the shelf wheels (e.g. Ithaco B wheel) would increase jitter still further and would require isolation.**

NGST END-TO-END MODELING

WAVEFRONT ERROR

Dave Redding

24 June 1997